VUF-3017
FINAL REPORT

VELA UNIFORM PROGRAM

PROJECT DRIBBLE

SALMON EVENT

TATUM SALT DOME, MISSISSIPPI

22 OCTOBER 1964

part of an experiment in seismic decoupling at the nuclear level

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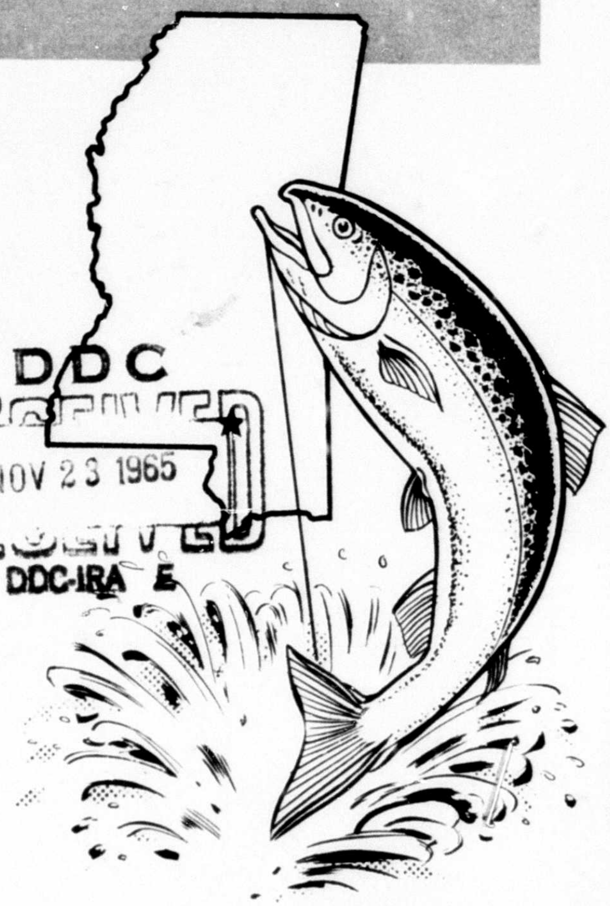

Feasibility of Cavity Pressure and Temperature Measurements for a Decoupled Nuclear Explosion

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ABSTRACT

PART I

A study was made of the feasibility of measuring the pressure produced at the wall of a 14.5-meter spherical cavity by a 0.1-kt nuclear explosion. Wave forms and peak pressures assumed were those from LRL SQUID Runs SCYTHE 100C and DRBL-56. It was concluded that it will be feasible to make the desired measurements, and an experiment plan is recommended that appears to promise the most useful results.

Gages and gage systems were examined with regard to time resolution, susceptibility to damage by ionizing radiation, and mechanical ruggedness. It was concluded that several systems, applied at the same time, give maximum probability of useful results. The recommended experiment plan therefore includes two types of "bar gages," a variable capacitance diaphragm gage, a low-frequency conventional gage at the end of a long tube, and velocity pickups at several ranges from the wall. The bar gages and the diaphragm gage measure the gas pressure at the wall directly. The gage at the end of a long tube has poor high frequency response but responds to static pressure and hence gives a measure of the "step pressure" in the cavity. The velocity pickups measure pressure indirectly by the relationship between velocity and pressure in an elastic medium.

This plan uses mostly commercially available components, and does not add any difficulty to the already difficult over-all experiment.

PART II

It is feasible to measure the temperature of hot air near the edge of an underground cavity in which a 0.1-kt nuclear explosion has occurred. Measurement of the relative brightness of the radiating air in bands 100A wide centered at 2500 and 3500A will give the temperature to ±8 percent if the brightness ratio is determined to ±20 percent. (Temperatures in the range 4000°K to 10,000°K are anticipated. An absolute brightness measurement in either or both channels gives an independent measure of

temperature. With existing sensors, temperature can be followed to 20 msec after detonation, using a 100-meter long x 0.1-meter diameter nitrogen-filled light pipe with a reflecting aluminum liner. If radiation detectors with response times shorter than 0.1 msec can be installed to survive the passage of the pressure wave, measurements to longer times are possible.

PREFACE

This report is presented in two parts. Part I, Feasibility of Cavity Pressure Measurements, is the work of L. M. Swift. Part II, Feasibility of Cavity Temperature Measurements, was prepared by T. O. Passell and S. Rubin, assisted by Richard I. Miller.

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INTRODUCTION

Background

SAND Event is a portion of Project DRIBBLE, which is being conducted under the auspices of the VELA UNIFORM Program, primarily to test the theory of decoupling by use of a cavity. The SAND Event is planned as a 100-ton (0.1-kt) nuclear explosion at the center of a spherical cavity having a radius of approximately 14.5 meters (47.5 feet). The medium in which the cavity is to be located is halite (rock salt), in an intrusive salt dome in southwestern Mississippi known as the Tatum Dome. The planned shot depth is 2000 feet. Other events will document the local and remote effects of tamped explosions in this medium; SAND is the only "decoupled" explosion presently planned for Project DRIBBLE.

For maximum usefulness of SAND Event, data should be obtained showing the motion and stresses in the medium, at the cavity wall, and at various distances, for comparison with similar data from other explosions in this and other media. Other projects are already planned for measurements at ranges of about 50 meters and greater; this project is concerned primarily with stresses, motions, and temperatures at the cavity wall. Gages at other ranges are recommended primarily for extrapolation to the wall.

The expected peak values of pressure and velocity and the frequency spectrum are higher than can be handled by gage systems presently in use, so other systems must be devised or adapted for use on this event. This effort constitutes Part I of the study reported here.

It is also desired to measure the temperature of the gas near the cavity wall. An evaluation of available techniques for making such measurements and the development of an experiment plan utilizing the most effective technique comprise Part II of the study.

Objectives

The objective of Part I of the study was to design a field measurement experiment using gage systems suitable for measuring the pressure-time history on the walls of the SAND cavity and for measuring the associated earth motions at and near the wall. These experiment plans were to be based on predictions derived by Lawrence Radiation Laboratory (LRL) from mathematical analyses and from extrapolations from other experimental data.

The objective of Part II was to design a measurement system for the temperature of hot, impure air near the wall of a spherical cavity (14-meter radius) for about 20 msec after the detonation of a 0.1-kt nuclear device in the cavity. The general objective here was to determine the feasibility of such measurement and to develop an appropriate experiment plan using the best available technique.

PART I

FEASIBILITY OF CAVITY PRESSURE MEASUREMENTS

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PREDICTIONS

The predictions pertinent to this experiment design are obtained largely from LRL calculations. Early predictions were from LRL Computer Code SQUID, Run SCYTHE 100C[1]* in early 1961; these data were modified by SQUID Run DRBL-56[2] and data derived from this run. Empirical predictions based on COWBOY and GNOME data were used in some cases to extend the predictions.

Pressures

The first pulse of pressure on the cavity wall is expected to have a peak value of about 1080 bars (16,000 psi). The form of the pulse will probably look much like that shown in Figure 1. The rise time

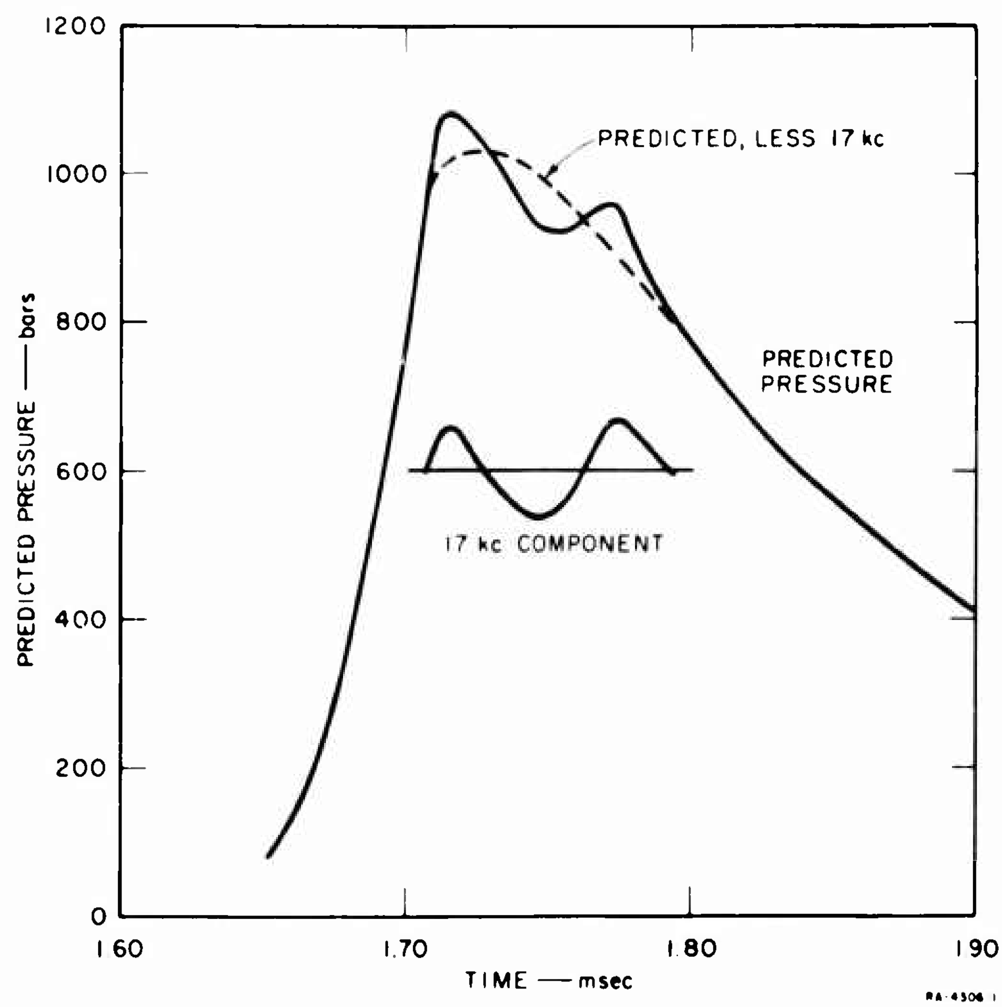


FIG. 1 PRESSURE VERSUS TIME, SQUID RUN DRBL-56

* Numbered references are listed at the end of this report.

in this prediction is about 45 μsec and the decay time is much longer, about 165 μsec. Either of these would be adequately handled by a system having a 10-kc response (35 μsec rise time), but the 17-kc wavelet near the peak requires at least 20-kc system response.

It is not entirely clear whether the 45 μsec rise time predicted is real or is a result of an artificial viscosity introduced into the program to make the iterative computer solutions converge. In any case, a 20-kc system will reproduce the actual input as faithfully as, or more faithfully than, the DRBL-56 run.

The first pulse is followed by a series of smaller pulses at intervals of about 5 msec, as shown in Figure 2. All these have rise times and half-peak durations much longer than the first pulse, and their

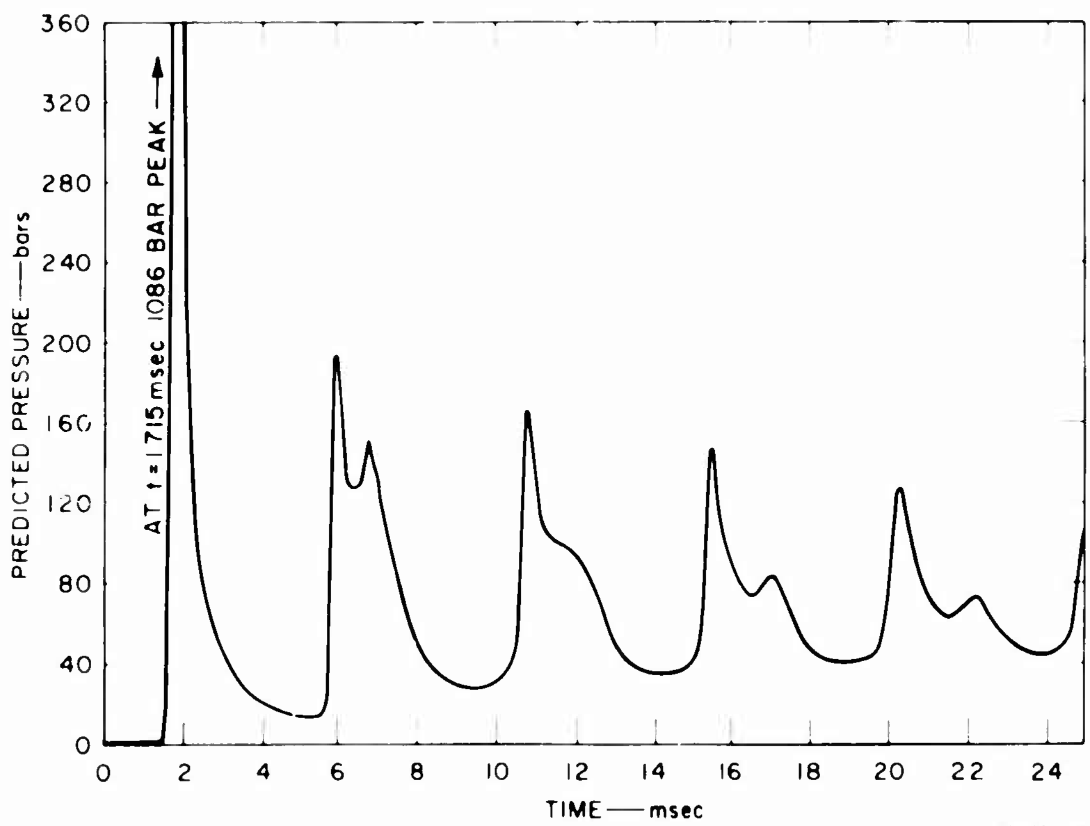


FIG. 2 PRESSURE VERSUS TIME IN ZONE NEXT TO WALL, SQUID RUN DRBL-56

secondary peaks are spaced by times of 0.8 msec or more. The amplitude of the first of these is only about 20 percent of that of the main peak, and the following peaks are, of course, lower. The average pressure about which these pulses oscillate--referred to at times as the "step pressure"--is expected to be 65 bars. This pressure will, of course, eventually bleed off and drop to zero, but over the period of 25 to 100 msec which is of primary interest, it will probably remain essentially unchanged.

Velocities

The DRBL-56 runs do not show particle velocities as such, but calculations based on known elastic characteristics and unidimensional theory show that early velocities will be proportional to the applied pressure, and the particle velocity, u, in centimeters per second, is approximately equal to the applied pressure in bars (u = 1 to 1.25 cm/sec/bar, depending on the variation of elastic constants between samples). We may expect, then, a peak velocity of 1080 to 1350 cm/sec, or 425 to 530 in./sec, at the wall of the cavity at a time of about 1.7 msec after zero time, with the same general frequency spectrum as the pressure signal at the wall. Later velocities will oscillate about zero, not about 65 cm/sec, as would be expected from unidimensional theory, which does not apply after a few milliseconds.

Preston's memorandum of 19 April 1963[3] shows empirically predicted changes in peak velocities as a function of distance outside the wall. He expresses the relationship as

$$u_p = 1.62 \times 10^4 R^{-1.256}$$

where u_p is the peak particle velocity in centimeters per second and R is the range in meters from the center of the cavity. At the cavity wall, this figure is 565 cm/sec, about one-half that calculated from the pressure. (Preston specifically warns against such extrapolation to this "unique" position.) In any case, we may accept the decay exponent of -1.256.

Displacements

SQUID Run DRBL-56 shows predicted displacement at the cavity to peak at about 0.3 cm at a time of about 1.3 msec after first arrival or 3 msec after zero time (see Figure 3). Subsequent peaks at intervals of about 5 msec are smaller than the first, but the contrast is much less than for pressure or velocity. The displacement minima are never negative; in fact they are never less than half the peak. After the first few cycles, the displacements oscillate about an average of about 0.165 cm, which is also the permanent displacement calculated for the "step pressure" of 65 bars.

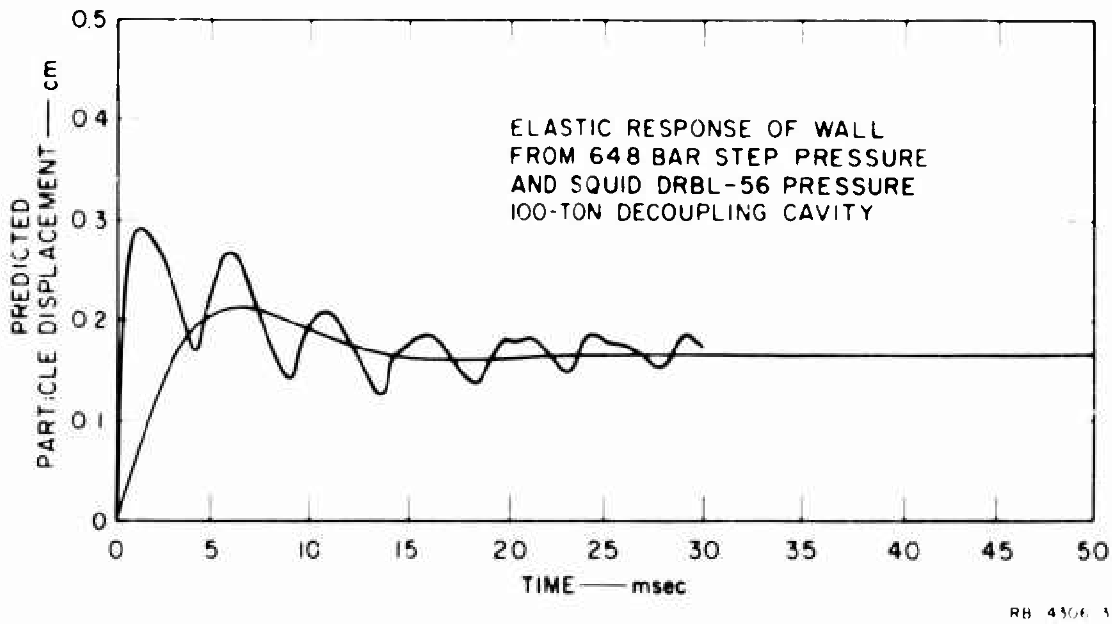


FIG. 3 DISPLACEMENT VERSUS TIME, SQUID RUN DRBL-56

The frequency spectrum of the transient displacements is much lower than that of pressure or velocity, as might be expected. These phenomena could be portrayed by a recording system with a cut-off above 500 cps.

The peak particle displacements also fall off as a function of range, outside the cavity. The decay exponent expected is about -1.12, less than that of peak velocity. The displacements produced by the "step pressure" of 65 bars are expected to decay with an exponent of -2. Eventually, as the pressure decreases to atmospheric, the displacements can be expected to return to zero, if the entire mechanism remains elastic in accord with expectations.

Strains

Strain predictions were not run directly on DRBL-56, but they can be derived readily from the pressures and the elastic constants. For a peak pressure at the wall of 1080 bars and a modulus of 2.25×10^5 bars, we may expect a peak strain of 0.0048, or about one-half of one percent. This peak strain drops off outside the cavity, presumably with the same decay exponent as the peak velocity, -1.256.

GAGES

The major part of this study involved the selection of gages and transducers which were believed to be suitable for use in this experiment. "Suitability" includes not only suitable range and frequency response, but also the ability to withstand or avoid the effects of this environment. The environment includes high levels of electromagnetic radiation (thermal to gamma) over a wide spectrum at the cavity wall, a very high neutron flux, and strong mechanical shock.

Pressure Gages

The phenomenon of primary interest is pressure at the cavity wall. It is desired to know the detailed pressure-time history of the entire performance, but that of the first pulse is especially important. Even the value of the first peak alone would be an important and useful bit of information. In addition, a pressure-time history spanning at least the first 5 seconds is desired, to document the step pressure and its decay. This measurement may have a poor time resolution, as high as 100 msec.

Several gages and gage systems have been examined and considered for these applications. Those of interest are:

General Atomics Bar Gage

The General Atomics Division of General Dynamics offers a standard item, the Model 5-250-260 pressure gage, which is sketched in Figure 4. This is one of several types of bar gages, which all operate on the principle of conducting the pressure pulse down an elastic bar to a sensor which can be shielded from the environment being examined. In this version, the end of a tungsten rod 1/4 inch in diameter and 24 inches long is exposed to the pressure being measured. The far end of this rod is joined to a similar magnesium rod through a thin quartz piezoelectric wafer, the sandwich being securely cemented together with an epoxy cement. The contrast between the acoustic impedances of the two rods causes the stress applied to the quartz crystal to be much lower than that in the first rod, so the crystal is not shattered

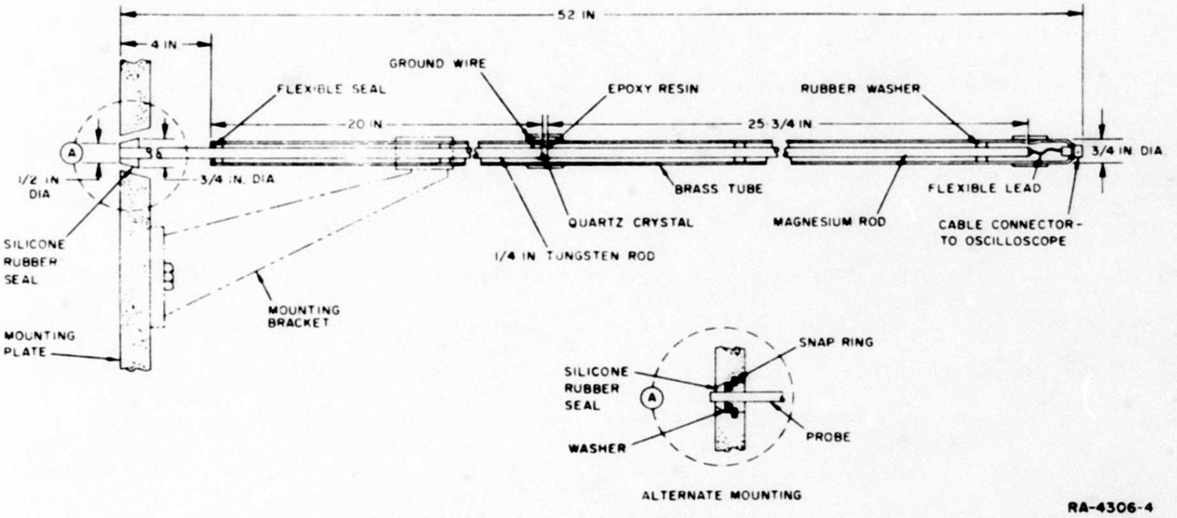


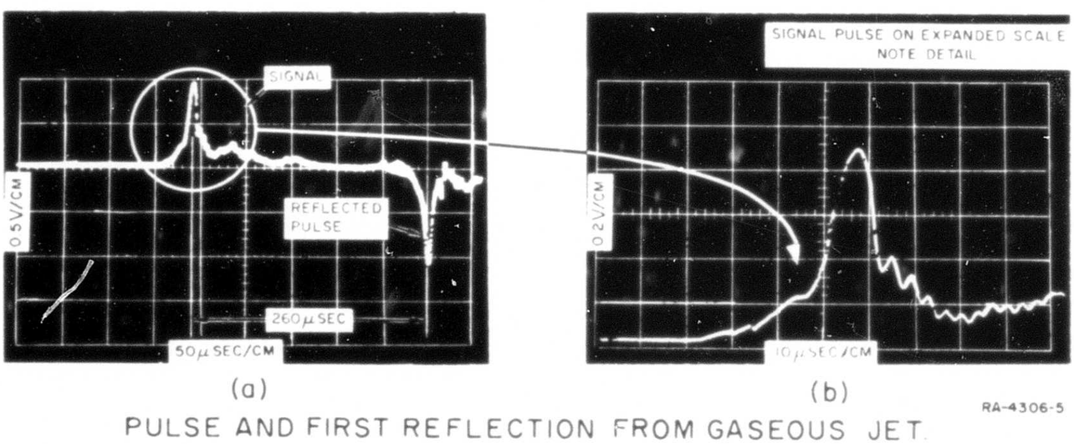
FIG. 4 SECTIONAL VIEW OF GENERAL ATOMICS BAR GAGE

by pressures up to 5 kilobars or more. The stress wave, of course, passes on into the magnesium rod at a reduced level, is reflected at its end, and returns to the position of the crystal, after which the output is disturbed by this reflection. In addition, the signal reaching the crystal from the tungsten rod is reflected at an only slightly reduced level, is again reflected from the front end, and returns to the crystal as a disturbance. The gage is proportioned to make these two travel times the same, using a 25-3/4-inch magnesium rod to match a 24-inch tungsten rod. This round trip time is 260 μsec, and this is the useful duration of the output of this gage.

The specified rise time of this gage is 2.5 μsec, which is much shorter than the 18 μsec which is considered the maximum allowable. Under normal operating conditions, the output voltage is over 1 volt per kilobar, a satisfactory level for transmission to the recorder.

The operation of this and other bar gages assumes that the signal is transmitted down the rod without distortion. This is not true. As DeVault points out in Reference 4, ". . . when the rate of loading is rapid, the resulting strain pulse spreads out during travel and develops oscillations which have no counterpart in the applied force." DeVault goes on to demonstrate that these oscillations produce an overshoot of as much as 20 percent in a typical case, and disturb the first part of the decay with poorly damped oscillations. However, an examination of records from the General Atomics gage shows that such oscillations do occur, as shown in Figure 5, but that in this gage they are over 250 kc, whereas our interest is not above about 20 kc. The oscillations can quite readily be filtered out with no loss of data.

The layout of this gage is such that the electrical components are shielded from gamma radiation by the tungsten rod and by its case, and the gage is purported to be quite resistant to nuclear radiation, but the manufacturer states that they do, if necessary, make a special radiation-resistant model which has ". . . a radiation sensitivity 1/10,000 that of the standard gage."



PULSE AND FIRST REFLECTION FROM GASEOUS JET
MAXIMUM PRESSURE IS 1.1 kilobars

FIG. 5 RESPONSE PATTERNS, GENERAL ATOMICS BAR GAGE

Custom Bar Gage

The Institute has facilities and experience to produce a simplified bar gage suitable for this application, having a longer duration of signal capability than the 260 μsec of the General Atomics gage. This SRI design would sacrifice resolution by accepting a rise time of about 10 μsec. This would allow the use of a continuous rod with one or more sensors located 4 feet or more from the sensing end for better shielding, and with at least 6 feet of rod beyond the sensor, allowing an operation time of some 750 μsec. It may be possible to extend the bar much farther, or to terminate it to avoid reflection, but the limit is probably 1 or 2 msec.

There may be some advantage in using two types of sensor on the same gage. The high-impedance piezoelectric sensor can be made to deliver a large signal, but it is sensitive both to the so-called "EM signal" at zero time and to the nuclear radiation. The low-impedance strain sensor puts out a smaller signal, but its sensitivity to outside sources is low, so its signal-to-noise ratio may be better. Without specific data on these disturbing radiations a choice may be impossible, so both types should be used, on two separate channels, but they may be on the same bar.

Photocon Gage

Photocon Research Products builds a gage system using a capacitive diaphragm gage with a tuned system operating at a carrier frequency of about 1 Mc, but the company rates the system output as flat to 10 kc only. Gage ranges are available for up to 6 kilobars. By protecting the sensing diaphragm by a two-diaphragm construction and by use of a perforated flame shield, this gage can be protected from high temperatures and thermal radiation. The Institute obtained a surface level airblast pressure-time record on one such gage at the 1200 psi level on SMALL BOY, but one located at the 5000 psi level failed to produce a record--presumably because of nuclear radiation effects.

It may be possible to add further shielding to such a gage, up to the point where the 10-kc frequency response is jeopardized, and to use the gage to measure the pressure-time history of the entire event.

Low-Resolution Gages

Wiancko and other variable-reluctance pressure gages used with a 3-kc carrier system are available in ranges up to 5000 psi, or 0.35 kilobars. When used with an input filter to remove spikes, such a gage is best adapted for measurement of the step pressure. The input filter may be a long, small-diameter tubing leading from the cavity wall to the gage 10 feet or more from the wall, thus providing the necessary shielding. No complications are anticipated.

Particle Velocity Gages

Although the primary objective of the planned experiment is to measure the time history of the pressure at the cavity wall, it is possible to derive such data indirectly from the measurement of other parameters such as stress, strain, or particle velocity. Such measurements would be useful even if they were taken at points a considerable distance (up to two or three cavity radii) from the wall. If reliable readings are obtained at several ranges, extrapolation to the cavity wall can be made empirically as well as analytically. For this reason, gages are included in the experiment plan as far out as 33 meters from the wall.

We have no gages or installation procedures for reliable measurement of stress or strain in the medium at these levels and frequencies. Velocity gages such as the SRI Mark I or Mark II gages are not applicable except at three or more cavity radii. They are limited by spurious response to or damage from shock as well as by limited high frequency response of the gages themselves and of the carrier system used with them. The only other type of velocity gage which seems applicable is the velocity pickup.

Velocity Pickup

The general class of instruments known as velocity pickups consists of spring-mass systems operating at frequencies above their undamped natural frequencies, so that the relative displacement between the mass and its case is essentially the same as the displacement of the case (the mass remains essentially stationary). The output is usually the voltage produced by the relative velocity of motion between a coil and a magnet, one of which is attached to the case and the other is a part of the seismic mass. The output, then, is proportional to the velocity of the case at frequencies well above the natural frequency and at amplitudes less than the limit of travel of the mass with respect to the case.

One type of velocity pickup which promises to be useful is the Consolidated Electrodynamics Corporation (CEC) Model 4-106H, shown in Figure 6. This device is a sprung-magnet type with a total travel of 0.5 inch. A sprung-magnet type was chosen because it needs no unsupported leads from the coil to the terminals. The resistance of the coil is 500 ohms and it is presumed that it was intended for a 500-ohm load at frequencies under 100 cps. The inductance as measured at 1 kc is 27 mh.

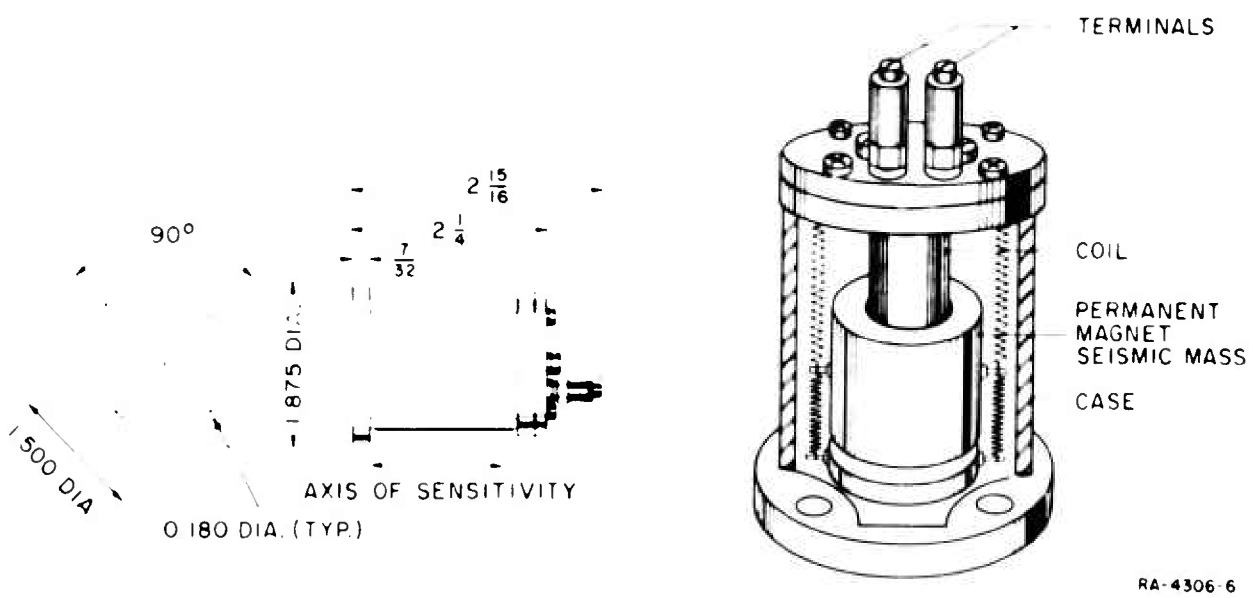


FIG. 6 CONSOLIDATED ELECTRODYNAMICS CORPORATION VELOCITY PICKUP TYPE 4-106H

The upper limit of frequency response of such a gage is set by the inductance of the coil, its distributed capacity, and the load into which it is operated. As built, this coil tends to be broadly resonant at 2.3 to 3.5 kc, even when working into a 500-ohm load. This was not tolerable, so one such gage was rewound with larger wire and fewer turns, resulting in an inductance of 1.4 mh. This assembly then was found to show no electrical resonant peaks and to be flat within 1 db to 200 kc when worked into a 500-ohm load.

This modified gage produces a voltage in the 500-ohm load of about 40 mv per inch per second of velocity. When subjected to the near wall velocity of about 500 in./sec predicted earlier, the peak signal would be 20 volts, a very respectable signal.

The low-frequency response limit is set by the natural frequency of 5 cps, which permits satisfactory operation at 10 cps and above. Very little signal is expected below about 50 cps.

The predicted displacement maximum is about 0.3 cm (0.12 in.) at the time of the first peak. This is only half the one-way allowable maximum of 0.25 inch, and this allowable maximum can be increased to nearly 0.5 inch if desired by adjustment of springs, since no negative displacements are expected.

It is probably optimistic to expect this type of gage to survive long under such severe shock as will be experienced near the cavity wall. Acceleration along the axis (radial from the shot) cannot injure it, but transverse shocks over about 50 g may damage it or cause a temporary malfunction. It seems probable that the first peak will be obtained reliably, and there is some chance of getting the first several peaks.

SRI-DASA Velocity Gages

Although the SRI Mark I and Mark II velocity gages are not suitable for this application, a program is presently under way to design a gage of this general type (over-damped accelerometer) having higher frequency response and higher shock resistance. This development will be complete before the SAND Event, but its outcome is not, of course, known at present.

TRANSMISSION AND RECORDING SYSTEMS

Transmission Systems

Piezoelectric Gages

Piezoelectric gages such as the General Atomics bar gage will work directly into a preamplifier which may be only a cathode follower, since the signal voltage will be fairly high. This preamplifier may be located only about 10 feet from the gage, since the 260 μsec duration of the General Atomics gage represents a travel of only about 4 feet of the shock wave in salt. The usable recording time is well past before the shock reaches the preamplifier.

Even if 1 or 2 msec useful time is obtained in a custom-built gage, this will require only about 30 feet of cable between the gage and the preamplifier.

The preamps will be designed to work into a standard coaxial cable, probably RG-8U. The length of this cable is unimportant provided it is terminated in the proper impedance.

Velocity Pickups

The CEC velocity pickups, modified, will work into a load of about 500 ohms. They will probably work into a matching transformer located about 100 to 200 feet away, which will match them to a 50-ohm coaxial cable. This transformer will also serve another purpose (described in the section on protection of the system).

Photocon Gages

These gages are designed to work with a coaxial cable of lengths up to 2500 feet, but we are informed that recent techniques have increased that limit to 3700 feet. The present plan calls for about 2700 feet to the recording station. The electronics components of this system may then be at the recording point.

Carrier System Gages

The Wiancko variable-reluctance gage used for measurement of the step pressure will use conventional 3- or 4-conductor shielded cables, as will the SRI-DASA velocity gages. Carrier oscillators and demodulators will be in the recording truck.

Recording Systems

Final recording of the gage systems will be on wide-band FM magnetic tape channels having an upper frequency limit of 20 kc. If still higher frequencies turn out to be desired, special voltage-controlled variable frequency oscillators can be obtained to extend this recording method to 50 kc or more, when used with the 1-Mc Min-Com tape systems now part of the DASA-owned equipment at SRI. A slower recorder may be used for recording the step pressure, since its variation over a period of many minutes may be important.

Protection of System

Protection from EM Transients

All conductors reaching into the cavity, and perhaps those close to the cavity, will pick up an EM transient at zero time which endangers the gage components and the recording system at the far end of the line.

This "induction signal," insofar as its effects on the circuits are concerned, consists of the establishment of a very high potential gradient in the earth along lines radial to the shot. The primary defense against this signal is shielding. Cable and gage shielding should be continuous, and should be grounded at one point only. Under the circumstances of this operation, that point must be at the recording point.

Other means of protection include the use of circuits which are not subject to overload, or which recover rapidly from overload, since the duration of this transient is short. The tube conducting the step pressure to the gage must be insulated from the gage itself by a coupling of insulating material.

A powerful means of protection is the use of an isolation transformer in the gage circuits at a distance of 50 to 200 feet from the gage. This transformer must be insulated for 5000 volts or more between windings and from windings to shield. The shield of the circuit including the gage and the transformer primary is connected to local earth at the gage or at the transformer, as shown in Figure 7. The shield of the circuit including the transformer secondary and the remaining cable and the recording equipment is grounded at the recording point.

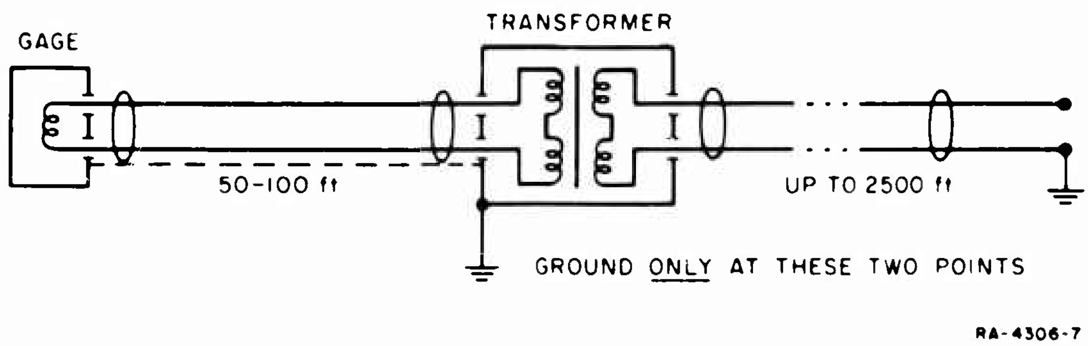


FIG. 7 USE OF ISOLATION TRANSFORMER

Other protective schemes may be required and developed for some specific situation.

Protection of Cable from Mechanical Effects

In most applications, mechanical damage to the gage cables near the gage and shot point is a major problem. This is not severe in this application. The salt is expected to behave elastically, so strains and shears greater than the cable can survive do not occur. The danger points are at junctions, where the cable passes into gage or junction box bodies, and here ordinary protective means are satisfactory.

Protection from Ionizing Radiation

One of the important problems is protection of the gages and gage cables from ionizing radiation and its side effects. The bar gages reduce this problem by moving the electrical sensors away from the sensing end of the bar, allowing for some two feet of shielding between the sensor and the tip. The "step pressure" gage obtains shielding in exchange for time resolution by conducting the pressure signal through a considerable length of small tubing. The velocity pickups need no connection with the cavity, and in their use we accept loss in accuracy in exchange for shielding. The Photocon gage can have only a moderate amount of shielding, probably a tungsten baffle about 1 inch thick.

Some of the general practices in protection against radiation include:

1. The use of means to locate electronic devices behind as much shielding as possible, as in the bar gage;
2. The use of tested radiation-resistant semiconductors and ferroelectric components;
3. The use of inorganic insulators or tested organics in the zones subject to radiation;
4. Not using air for insulation in a radiation field, and instead, filling open cavities with an insulating fluid or potting compound.

These practices will be followed wherever possible.

RECOMMENDED EXPERIMENT PLAN

This study of transducer principles and available gages leads to the conclusion that a satisfactory experiment can be conducted to measure the pressure at the cavity wall, as well as related phenomena. This can best be done by using several different parameters as a measure of the cavity wall pressure and response.

It is not certain at the present time just what the geometry in the vicinity of the cavity will be, but it is assumed that it will be somewhat as sketched in Figure 8. A vertical shaft large enough for personnel access will pass near the cavity wall and will connect to it with a horizontal drift. A short cross-drift is used for drilling holes to the cavity. It is expected that access will be had to the cavity face at the inner ends of the holes, as well as to the outer end.

The one hole shown drilled from the vertical shaft for gages 5VR1 and 5VR2 may not be practical. If not, an extension of the hole used for 4VR1 to reach a radial range of 33 meters will be satisfactory.

Table I shows this same gage layout including predicted peak values to be used for range setting and the required frequency response of the recording system, as discussed earlier.

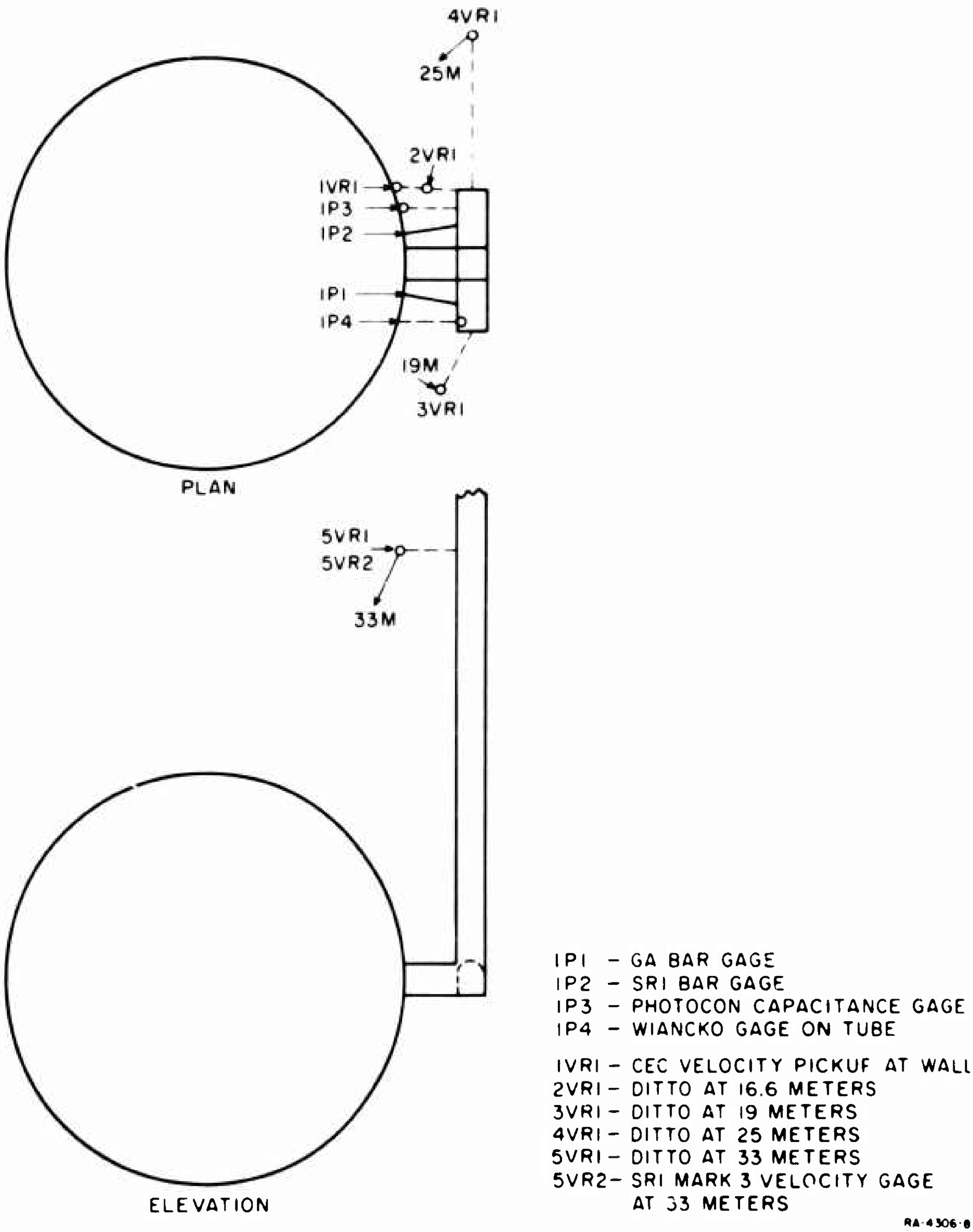


FIG. 8 SCHEMATIC DIAGRAM OF SAND CAVITY GAGE PLAN

TABLE I TENTATIVE GAGE LAYOUT

Gage	Slant Range [a]		Predicted Peak	Frequency Response	Description
	meters	ft		cps	
1P1	14.5	47.5	1080 bars	10 - 20k	General Atomics bar gage
1P2A	14.5	47.5	1080 bars	10 - 20k	SRI custom bar gage - piezo sensor
1P2B	14.5	47.5	1080 bars	10 - 20k	SRI custom bar gage strain sensor
1P3	14.5	47.5	1080 bars	0 - 10k	Photocon capacitance gage
1P4	14.5	47.5	65 bars	0 - 100	Wiancko gage on tube - step pressure
1VR1	14.6	47.8	10 m/sec	10 - 20k	Velocity pickup
2VR1	16.6	54.5	8.4 m/sec	10 - 20k	Velocity pickup
3VR1	19	62.4	7 m/sec	10 - 20k	Velocity pickup
4VR1	25	82.	5 m/sec	10 - 20k	Velocity pickup
5VR1	33	108.	3.5 m/sec	10 - 20k	Velocity pickup
5VR2	33	108.	3.5 m/sec	0 - 1000	SRI Mark III velocity gage

[a] Greater ranges, to 200 meters subsurface and to 640 meters on surface, are planned for other objectives.

PART II

FEASIBILITY OF CAVITY TEMPERATURE MEASUREMENTS

PREDICTIONS

This part of the report deals with cavity temperature measurements for a 0.1-kiloton nuclear device detonated in a spherical cavity of 14 meters' radius. We wish to measure the temperature of hot, impure air near the wall of this cavity for about 20 msec after shot time. The temperatures expected range from about 4000 to 10,000°K.[1*] The heated gas near the cavity wall will be mostly air but with some admixture of nuclear device materials and salt. Assuming one (1) atmosphere initial air pressure in the cavity, the mass of air is approximately 13,000 kilograms. A rough upper limit to the mass of the 0.1-kiloton device is about 1700 kilograms.[1] No estimate of the mass of salt vaporized is available. Because of the uncertainty in the degree of air contamination, a measurement method was chosen which is not sensitive to the impurity level.

The pressure and temperature near the cavity wall are predicted to undergo oscillations with a period of approximately 10 msec (not sine wave).[1] Thus one might expect to observe two or possibly three temperature peaks near the cavity wall during 20 msec of active measurement. Since the half-width of the initial peak is predicted to be about 0.5 msec, the measuring technique must have a time response of 0.1 msec or less to follow these oscillations.

The following section of this report will describe one approach to this difficult measurement problem.

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* Descriptions of expected yield, temperature, device weight, and time for various phenomena are all taken from Reference 1.

METHOD OF TEMPERATURE MEASUREMENT

In the temperature range above $4000^{\circ}K$, the only practical method for measuring temperature utilizes the radiant energy emitted from the heated body. The radiant emission of heated air is determined by two main variables--its temperature and its opacity. If a body is thick enough or dense enough to be opaque to its own radiations, it will radiate energy at a rate which obeys the Stefan-Boltzmann equation:

$$P = \sigma T^4 \tag{1}$$

where P is the power radiated per unit area of the body, in watts-cm^{-2},

σ is the Stefan-Boltzmann constant (5.67×10^{-12} watts-cm^{-2} $^{\circ}K^{-4}$),

and T is the temperature of the surface in $^{\circ}K$.

If the body is transparent to its own radiations, Equation (1) becomes

$$P = (1-\exp\left[-\mu L\right])\sigma T^4 \tag{2}$$

or for μL much less than 1

$$P \cong (\mu L)\sigma T^4 \tag{3}$$

where μ is the mean absorption coefficient of the body averaged over the Planck distribution, and

L is the characteristic thickness of the body.

For a reliable measurement it would be well to select only those spectral regions where the heated air is effectively opaque, thus relieving one from the requirement of knowing μL precisely.

The spectrum of radiant emission from a black-body varies with temperature as described by the Planck radiation law

$$N_{\lambda} = C_1 \lambda^{-5}\left[\exp\left(C_2/\lambda T\right)-1\right]^{-1} \text{ watts cm}^{-2}\text{ster}^{-1}\text{cm}^{-1} \tag{4}$$

where N_{λ} is the spectral radiance, defined as the radiant flux emitted per unit solid angle per unit projected area of the black-body per wavelength interval,

λ is the wavelength of the radiation in cm,

$C_1 = 1.9 \times 10^{-12}$ watt-$cm^2 ster^{-1}$,

T is the absolute temperature in $^{\circ}K$, and

$C_2 = 1.438$ cm-$^{\circ}K$.

Figure 9 shows graphically how the spectral radiance (N_λ) of a black-body varies with wavelength for temperatures from 3000 to 10,000°K. The spectral shift toward shorter wavelengths as the temperature increases is quite apparent.

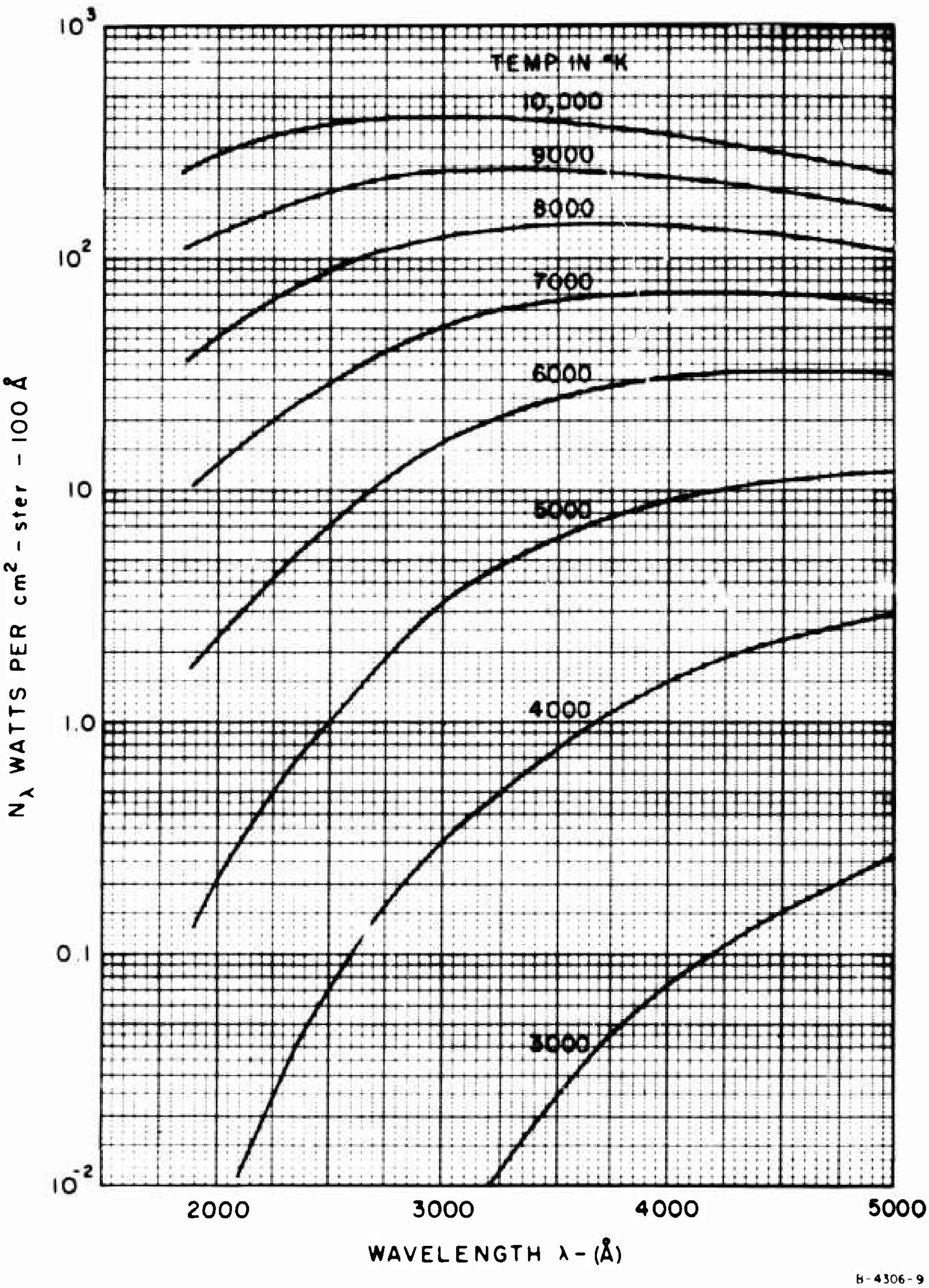

FIG. 9 SPECTRAL RADIANCE OF A BLACK-BODY AT 1000° INTERVALS FROM 3000° K TO 10,000° K

To simplify experimental procedures and calculations, one wishes to find regions of the hot air emission spectrum in which the air is opaque throughout the range of temperature of interest (4000 to 10,000^{o}K). The absorption coefficients for air as a function of temperature and the wavelength of the emission have been published as a set of tables.[5] Although these tables have been computed from theoretical arguments, they have been experimentally corroborated[6] in a few regions of temperature and density. The information in Figure 10 and Table II (taken from the published tables) indicate that the region from 2000A to 3500A is suitably opaque.

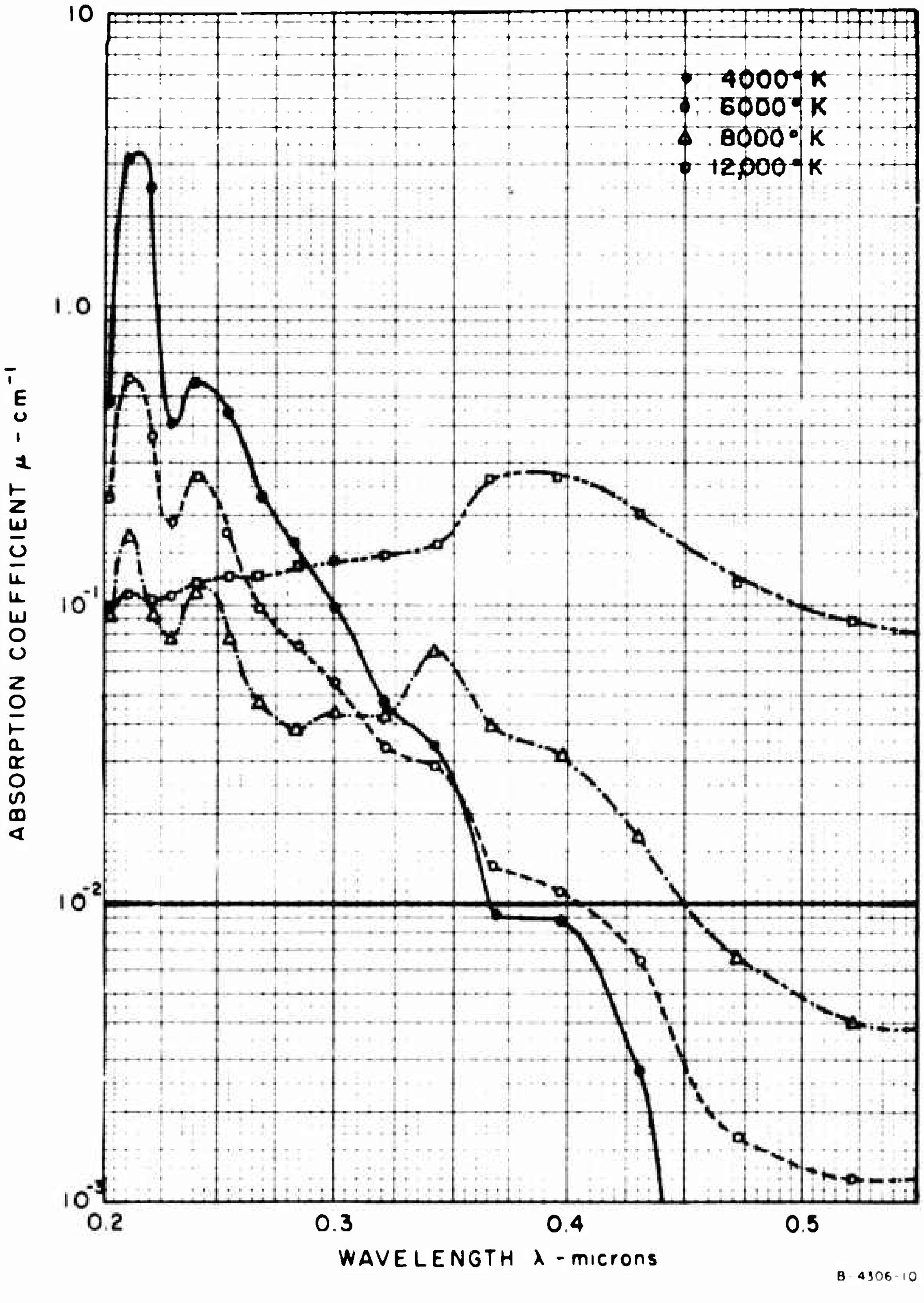

FIG. 10 ABSORPTION COEFFICIENTS OF 4000 TO 12,000°K AIR IN THE WAVELENGTH RANGE 2000 TO 5500A FOR A DENSITY IDENTICAL WITH THAT OF AIR AT STP

TABLE II ABSORPTION COEFFICIENTS OF AIR AT $\rho/\rho_0 = 1$ FOR 4000, 6000, 8000, and 12,000°K OVER THE WAVELENGTH RANGE 2000 to 10,000A*

Wavelength, λ (A)	Absorption Coefficient μ (cm^{-1}) for Air at			
	4000°K	6000°K	8000°K	12,000°K
2024	4.88(-1)	2.32(-1)	9.32(-2)	9.77(-2)
2110	3.21 (0)	5.82(-1)	1.69(-1)	1.08(-1)
2204	2.49 (0)	3.74(-1)	9.29(-2)	1.01(-1)
2307	3.98(-1)	1.84(-1)	7.83(-2)	1.06(-1)
2419	5.[illegible]7(-1)	2.76(-1)	1.19(-1)	1.11(-1)
2543	4.39(-1)	1.73(-1)	7.91(-2)	1.23(-1)
2681	2.29(-1)	9.82(-2)	4.76(-2)	1.22(-1)
2834	1.62(-1)	7.11(-2)	3.75(-2)	1.36(-1)
3006	9.88(-2)	5.55(-2)	4.39(-2)	1.35(-1)
3199	4.68(-2)	3.30(-2)	4.30(-2)	1.48(-1)
3420	3.45(-2)	2.92(-2)	6.97(-2)	1.53(-1)
3673	9.22(-3)	1.35(-2)	3.92(-2)	2.68(-1)
3967	8.89(-3)	1.11(-2)	3.08(-2)	2.72(-1)
4312	2.75(-3)	6.55(-3)	1.69(-2)	2.03(-1)
4723	5.18(-5)	1.63(-3)	6.63(-3)	1.18(-1)
5220	9.29(-6)	1.21(-3)	3.98(-3)	8.80(-2)
5834	8.32(-7)	1.48(-3)	4.81(-3)	1.10(-1)
6612	2.27(-6)	1.79(-3)	6.23(-3)	1.48(-1)
7630	3.78(-6)	1.95(-3)	7.06(-3)	1.79(-1)
9016	4.23(-6)	1.16(-3)	4.49(-3)	1.47(-1)

* Numbers in parentheses indicate the power of 10 by which the number is multiplied.

We may take two possible approaches in determining the temperature of a black-body radiator. The first and preferred method is to observe the relative emission of the body at two separated bands of wavelengths, the ratio between these being sensitive to the temperature. A second technique is to measure the absolute radiant intensity at any one wavelength band. One advantage of the first technique is the absence of any requirement for an absolute measurement. However, the required accuracy of any absolute measurement is not severe because of the enormously strong ($I \propto T^6 \rightarrow T^8$) dependence of that intensity on temperature. Obviously if both channels in the relative measurement also provided absolute energy measurement, we would have three independent measures of the temperature.

Either approach requires a set of radiation-detection instruments preceded by filters to select the proper wavelength regions. The instruments must remain operative for about 20 msec, so a light pipe is needed to separate the detectors from the initial blast zone. Since the induced pressure wave travels at a rate of about 15 ft/msec in the salt medium in which the experiment will be performed, 20 msec of freedom from shock for the instrumentation requires a light pipe some 300 feet in length.

BASIC DESIGN OF EXPERIMENT

The first task in designing the experiment is to determine the wavelength region where the available path length within the hot air layer is sufficiently opaque to be considered a black-body radiator. Inspection of Table II and Figure 10, and consideration of such practical experimental limitations as the transmissivity of quartz, lead to a choice of the wavelength region 2000 to 3500A for all measurements. The upper limit is determined by the fact that the absorption coefficient of $4000^{o}K$ air (at a density equal to that of the normal atmosphere) drops below 10^{-2} cm^{-1} at 3500A. The lower wavelength limit is set by the transmission characteristics of the optical system. It is roughly the limit for an optical system based on quartz windows and gas-filled, aluminum-surfaced, light pipes.

The value of 10^{-2} cm^{-1} was chosen as the lower limit of allowable absorption coefficient by the following argument. The hot air may be distributed in many ways during the 20-msec measurement. Let us consider two extreme cases--one in which the gas is uniformly distributed throughout the spherical cavity, and another in which it is compressed into a thin layer at the cavity wall. In the uniformly distributed state, the maximum path length (along a diameter) would be 28 meters. In the second state, the equivalent path length would be $28/3 = 9.3$ meters of normal density air.

Since the optical system should be aimed along a chord of the sphere rather than through its center, to minimize nuclear radiation background, one would choose a line of sight such that the source thickness is at least 5 mean free paths (5 meters for an absorption coefficient of 10^{-2} cm^{-1}) of the radiation to be observed.

Five mean free paths (or radiation lengths) was arbitrarily chosen as the minimum acceptable source thickness for the assumption of a "black-body." Therefore, with a 5-meter path in air of standard density (or its equivalent) the minimum allowable absorption coefficient is 10^{-2} cm^{-1}.

The Light Pipe

It is known that a shiny aluminum surface is a fairly good reflector of incident radiation in the wavelength range above 2000A.[7] Also, many gases are transparent to photons in this wavelength region.[8-12] We envision for the light pipe a 100-meter length of gas-tight steel pipe lined with loose-fitting thin sleeves made of "one side bright" aluminum, with the bright side the interior surface. To protect the shiny aluminum finish from water vapor and oxygen attack, a filling of the inert gases helium or argon would appear to be satisfactory. Dry nitrogen also may be adequate. (These gases are transparent above 2000A except for some very sharp resonance lines which would block an insignificant fraction of the radiant energy.) The light pipe would be made of sufficient diameter (about 10 cm) to require only 4 to 10 reflections of the light in its traversal of the 100-meter length. The use of a light pipe of this type makes the problem of alignment easier, since small changes in alignment do not critically affect its transmission of light. (On the other hand, a lens system would be extremely sensitive to very slight shocks, even those caused by workmen in adjacent areas.)

The steel pipe would be placed in an oversize drill hole in the salt, to minimize distortion caused by deformation of the medium during the recording period. The loose fit of the reflecting tubing within the pipe might also help in decoupling it from pressure waves transmitted along the pipe from its attachment near the cavity wall.

Since this installation will be situated in a region where the surrounding rock salt will not be strained beyond its elastic limit, it appears reasonable that the pipe assembly and the support can be designed so that distortion caused by the pressure wave will not be sufficient to influence the light transmission.

Figure 11 is a preliminary sketch of a proposed experimental arrangement. The vertical or near-vertical orientation of the light pipe is unlikely to collect dust or other materials which might interfere with the reflectivity of the shiny inside surface. Mirrors at the detector end of the light pipe reflect the light around two corners, thereby reducing any direct nuclear radiation that might interfere with the measurement.

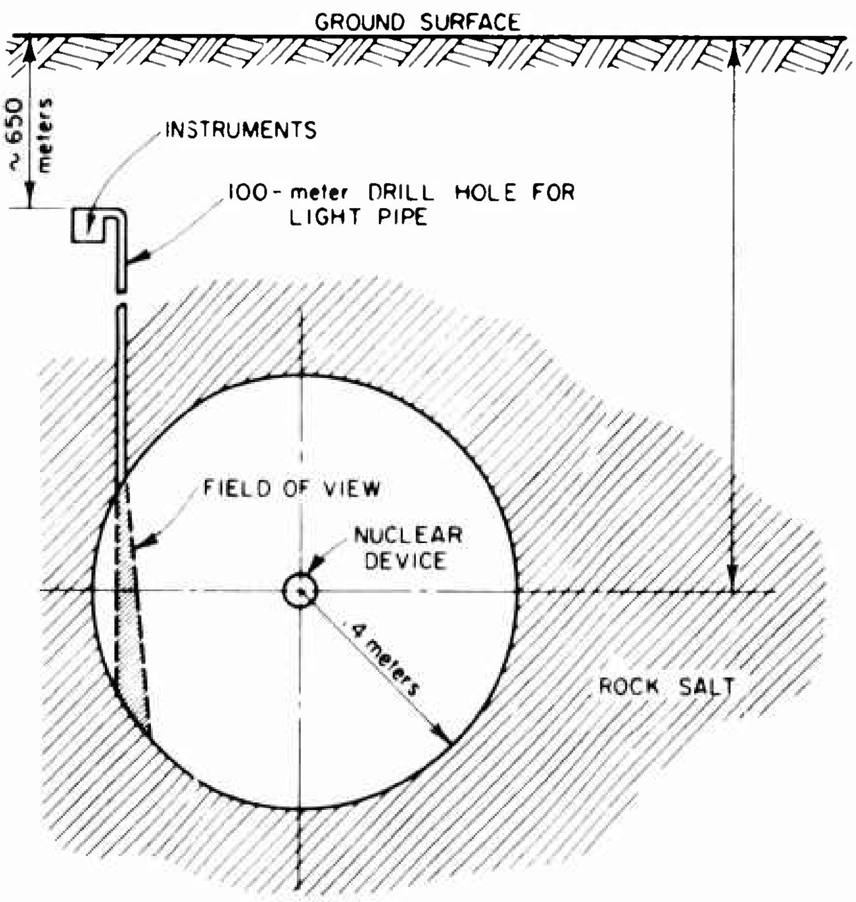

FIG. 11 PROPOSED EXPERIMENT ARRANGEMENT FOR MEASUREMENT OF TEMPERATURE

Figure 12 shows details of the junction of the light pipe and the cavity. The light pipe is isolated from the cavity by a quartz window designed to withstand pressures as high as 10 to 20 kilobars.[13] The optics of the system would be arranged so that the inner surface of the steel taper plug is not observed at the far end of the light pipe.

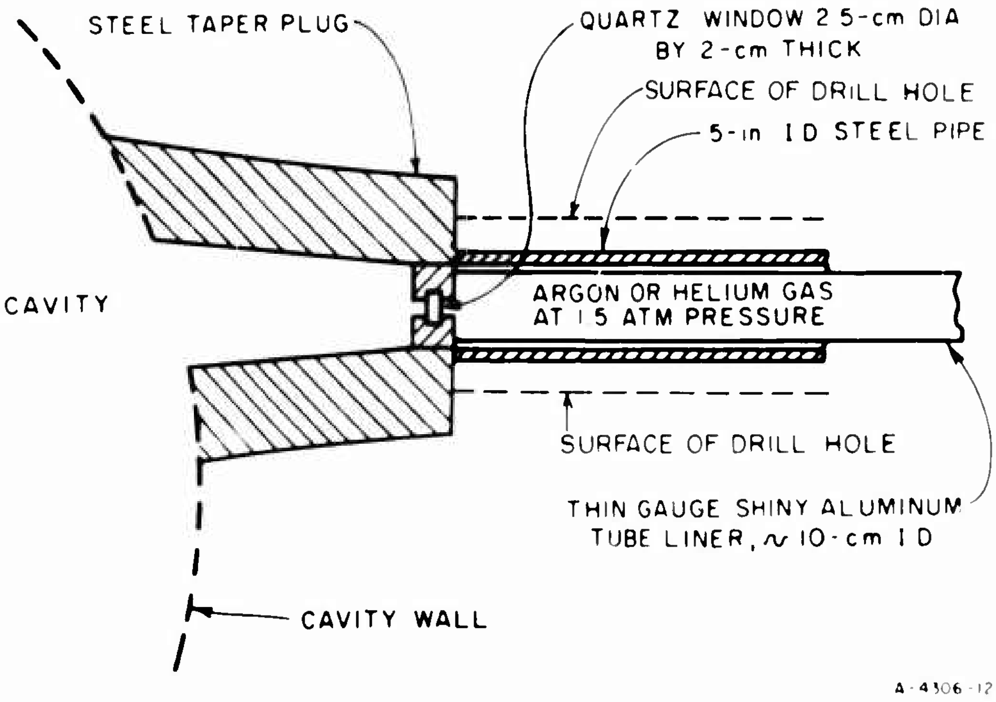

FIG. 12 DETAILS OF PROPOSED JUNCTION OF LIGHT PIPE AT CAVITY WALL

An aperture stop in the pipe will determine the maximum number of wall reflections required to transmit light to the detectors (Figure 13). We have specified a maximum of four reflections in order to make the transmission relatively insensitive to the wall reflectivity. A light pipe so designed corresponds to a lens system with aperture f/125, and provides a solid angle of about 5 x 10^{-5} ster. Light losses, such as absorption in the quartz window at the cavity end, absorption in the optics and filters at the instrumentation end, reflection losses, and restricted size of the detectors which reduce the effective light collection area, might decrease the energy received at the instrument by at least one order of magnitude and perhaps as much as two. For convenience in making calculations, we assume this over-all loss factor to be 0.02, thus reducing the effective solid angle to approximately 10^{-6} ster.

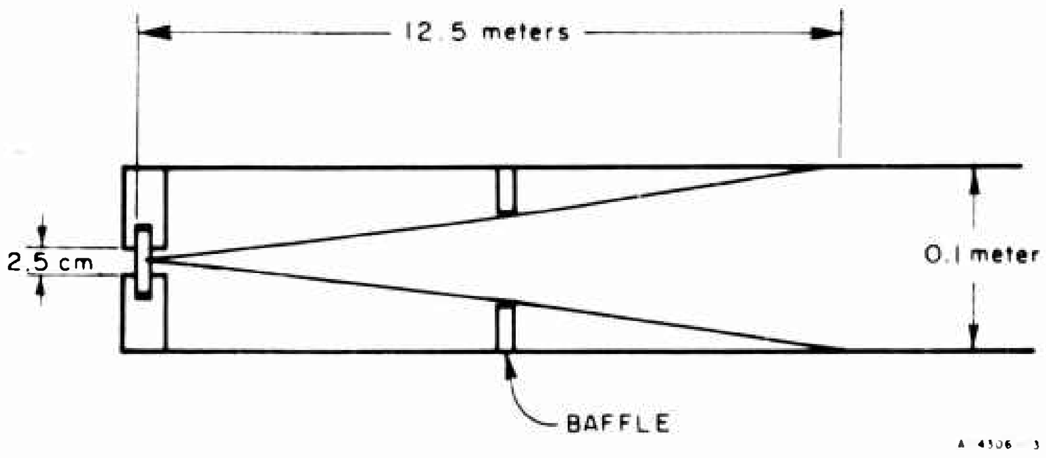

FIG. 13 ILLUSTRATION OF A GEOMETRICAL APERTURE WHICH ALLOWS UP TO FOUR WALL REFLECTIONS ALONG A 100-METER LIGHT PIPE

If ablation or fracturing of the quartz window proves too difficult to overcome, an alternative buffer zone may be created using helium gas. With a rupture disc or fast-opening valve at the cavity end of the light pipe and a quartz window near the detector end of the light pipe, helium gas at a pressure slightly above the expected peak air pressure would flow from the light pipe into the cavity after detonation. Even if the helium near the fireball boundary were heated, it would remain sufficiently transparent to avoid masking the high temperature region being probed.

The influence of the light pipe upon the probability of fission debris venting has been judged to be insignificant, relative to other available venting avenues (in particular, the main instrumentation shaft).

The Radiation Selection and Detection System

A choice must be made of two subregions in the selected 2000 to 3500A band for a two-color temperature measurement. For preliminary evaluation, the two subregions 2450 to 2550A and 3450 to 3550A were chosen.

Table III shows the spectral radiance in these two wavelength regions. At 10,000°K the gas will radiate 390 watts-cm^{-2}-100A-ster at 2500A. This value will decrease to 0.07 at a temperature of 4000°K, so the detecting and recording instrumentation must have a dynamic range of at least 10^4.

TABLE III VARIATION OF THE ABSOLUTE AND RELATIVE BLACK-BODY SPECTRAL RADIANCES IN THE TWO 100A BANDS CENTERED AT 2500 AND 3500A

Temperature ^{0}K	Spectral Radiance N_λ (watts/cm²-100A-ster) at wavelengths of 2500A	3500A	Brightness Ratio (3500/2500A) (each band 100A wide)
10,000	390	380	0.97
8,000	92	135	1.47
6,000	8.40	24	2.86
4,000	0.07	0.8	11.40

To calculate the power incident upon the detecting device, the radiances of Table III must be multiplied by 5 x 10^{-6} (area of quartz window $\cong$ 5 cm^2, effective solid angle including transmission losses $\cong 10^{-6}$). Power delivered to the detector region thus ranges from 0.35 to 2000 μw over a light pipe cross-sectional area of 78 cm^2.

Also shown in Table III are the ratios of spectral emittances from the 3500 and 2500A wavelength regions as a function of temperature. Between 4000 and 10,000^{0}K, the ratio between these two wavelength regions changes by a factor of about 12. Over the temperature region to be measured, a 20 percent uncertainty in this ratio gives roughly an 8 percent uncertainty in the measured temperature.

Table IV shows the sensitivity of various radiant energy detectors considered appropriate to the problem. Of these, only the photomultiplier has sufficient sensitivity to give a usefully large signal for the 4000^{0}K, 2500A incident power of approximately 0.35 μw/78 cm^2 (pipe area). The small size of the bolometer (1 x 1 mm) makes the focusing of the beam and loss of effective area severe problems, and so rules out this device. While the size (5 x 5 mm) of the PbS photoconductor cell is greater than that of the bolometer, its background noise is at least an order of magnitude too great for the measurement of the 0.35 μw signal. The photomultiplier tube, having at least 10^5 more available gain than is necessary and a dynamic range of greater than 10^5 in which it gives a linear response, is the only detector of the three considered which appears to have the requisite properties.

TABLE IV SENSITIVITY AND NOISE CHARACTERISTICS OF RADIATION DETECTORS CONSIDERED FOR THE TEMPERATURE MEASUREMENT

Detector	Sensitivity in 2500-3500A Range	Time Response (msec)	Noise Equivalent Power* (μwatts)	Size
Multiplier phototube	.3 amp/μwatt	10^{-5}	10^{-6}	15 cm^2
Thin film thermistor bolometer	100 volts/watt per 100 volts bias	1	0.2	1 x 1 mm
PbS photoconductive cell	10^4 volts/watt	0.1	5.0	5 x 5 mm

* Minimum expected signal at 4000°K is 0.35 μwatt over the 78 cm^2 area of the light pipe

Table V lists some possible wavelength filters for selecting a 100A bandwidth centered about 2500 and 3500A. The most likely choices would appear to be either the quartz monochrometer or commercially available ultraviolet filters.

TABLE V POSSIBLE WAVELENGTH FILTERS FOR SELECTING 100A BANDS AT 2500 AND 3500A

Type of Filter	Width of Transmission Window at 1/2 Peak Transmission
Quartz monochrometer	Variable from 6-120A at 2500A and 20-400A at 3500A
Aqueous solution of $CuSO_4$, $NiSO_4$, and $CoSO_4$ in series with solutions of organic materials	Generally not variable below 200A
Commercial UV filters (Baird Atomic) Types A-10, A-11, A-20, A-21, A-30, A-31	~100 to 200A

Calibrations

The proposed system of measurement is sensitive to changes that might occur in the reflectivity of the walls of the long light pipes. Therefore some means must be provided for monitoring such changes in the field. Possible devices for this purpose are the mercury arc lamp and xenon arc flash lamp. These would be placed in the cavity itself and flashed just before shot time to give a reliable calibration of the light pipe transmission. A low-sensitivity light detector near the lamps in the cavity may be required to monitor lamp output. The effective temperature of such lamps lies in the 4000 to 10,000^{o}K range; by using a condenser lens or mirror, one can obtain sufficient intensity at the detectors. (These calibration lamps would also provide the means for making dry runs of [illegible] detection and recording system.)

A steady, isotope-powered scintillation light source piped via short glass-fiber light guides to the detectors will serve [illegible] secondary absolute standard of light intensity.

The absolute sensitivity calibration of the photomultiplier could be carried out most conveniently in the laboratory using the same calibrating flash lamps, with absolute calorimeters near the lamp and with the photomultipliers at long distance to decrease the light intensity by a known factor to a range compatible with the photomultipliers' sensitivity.

SUMMARY

Calculations based upon the properties of air at a density near that of 1 standard atmosphere and at temperatures from 4000 to 10,000^{o}K show that it is possible to observe the radiant emission and thereby determine the temperature of a layer of hot air, some five or more meters in thickness. An absolute measurement of the radiant energy at one wavelength or the relative measurement of the radiant intensity at two or more wavelengths will give a measurement of the temperature of the body of air. Although many difficult experimental problems can be foreseen, there appears to be no fundamental difficulty that would make the project unfeasible.

The basic approach chosen is the piping of the light to a sufficient distance from the cavity that the pressure wave would arrive after the measurements were complete. The major uncertainty in this approach is the effect of the advancing wave on the light transmission of the 100-meter light pipe. Slight deformation or bending should not affect greatly the transmission of the light pipe, but intensive crinkling of the shiny inside surface might give large and unpredictable changes. If the long light pipe appears vulnerable to the pressure wave, alternate systems using much shorter light pipes and lower sensitivity, in conjunction with more rugged instruments, might be preferable over the proposed approach.

In either case, the light pipe would be isolated from the main cavity by a specially designed quartz window, designed to hold a differential pressure well in excess of the required 2 kilobars. Even if the window were directly exposed to radiation from a 0.1-kiloton detonation, the radiation damage from gamma rays and neutrons would be insufficient to cause appreciable change in its optical properties. However, for other reasons the light pipe and the window would be exposed only to a 5-meter chord along the edge of the spherical cavity; hence radiation damage or alteration of the quartz window should be entirely negligible.

REFERENCES

1. Preston, R. G. and W. M. Adams; "Predicted Phenomenology and Effects for Project DRIBBLE Test Detonations"; Progress Report No. 2, VELA-Uniform Explosion Series; UOPAC 61-134; May 9, 1961; Lawrence Radiation Laboratory; Livermore, California.

2. Patterson, Dan; "Project DRIBBLE and Associated Calculations for Decoupling"; September 13, 1963; Lawrence Radiation Laboratory; Livermore, California.

3. Preston, R. G.; Lawrence Radiation Laboratory, Livermore, California; Memorandum, Subject: "Empirical Predictions of Peak Particle Velocities from SAND Event, Project DRIBBLE"; 19 April 1963.

4. DeVault, G. P.; "An Elastic Bar Transducer for Measuring Spherical and Cylindrical Shock Wave Pressures"; Technical Memorandum SCTM 291-61(51); September 1961; Sandia Corporation; Albuquerque, New Mexico.

5. Meyerott, R. E., J. Sokoloff, and R. A. Nicholls; "Absorption Coefficients of Air"; LMSD-288052; September 1959.

6. Keck, J. C , J. C. Camm, B. Kivel, and T. Wentink, Jr.; "Radiation from Hot Air"; Annals of Physics 7, 1-38 (1959).

7. Sabine, J. B.; "Reflectivities of Evaporated Metal Films in the Near and Far Ultraviolet"; Phys. Rev. 55, 1064 (1939).

8. Boyce, J. C.; "Spectroscopy in the Vacuum Ultraviolet"; Red. Mod. Phys. 13, 1-40 (1941).

9. Ditchburn, R. W.; "Absorption of Ultraviolet Radiation by the Atmospheric Gases"; Proc. Roy. Soc. (London) A236, 216-226 (1956).

10. Lee, Po and G. L. Weissler; "Absorption Cross Section of Helium and Argon in the Extreme Ultraviolet"; Phys. Rev. 99, 540-542 (1955).

11. Wainfan, N., W. C. Walker, and G. L. Weissler; "Photoionization Efficiencies and Cross Sections in O_2, N_2, CO_2, H_2O, H_2, and CH_4"; Phys. Rev. 99, 542-549 (1955).

12. Weissler, G. L., Po Lee, and E. I. Mohr; "Absolute Absorption Coefficients of Nitrogen in the Vacuum Ultraviolet"; Jour. Opt. Soc. Amer. 42, 84-90 (1952).

13. Poulter, T. C.; "Apparatus for Optical Studies at High Pressure"; Phys. Rev. 40, 860-871 (1932).

TECHNICAL AND SAFETY PROGRAM REPORTS SCHEDULED FOR ISSUANCE BY AGENCIES PARTICIPATING IN PROJECT DRIBBLE

SAFETY REPORTS

Agency	Report No.	Subject or Title
USWB	VUF-1020	Meteorological Documentation and Radiation Protection
USPHS	VUF-1021	Final Report of Off-site Surveillance
USBM	VUF-1022	Pre and Post-Shot Safety Inspection of Oil and Gas Facilities Near Project Dribble
USGS	VUF-1023	Analysis of Geohydrology of Tatum Salt Dome
USGS	VUF-1024	Analysis of Aquifer Response
REECo	VUF-1025	On-Site Health and Safety Report
RFB, Inc.	VUF-1026	Analysis of Dribble Data on Ground Motion and Containment - Safety Program
H-NSC	VUF-1027	Ground Water Supply
FAA	VUF-1028	Federal Aviation Agency Airspace Advisory
H&N	VUF-1029	Summary of Pre and Post-Shot Structural Survey Reports
JAB	VUF-1030	Structural Response of Residential-Type Test Structures in Close Proximity to an Underground Nuclear Detonation
JAB	VUF-1031	Structural Response of Tall Industrial and Residential Structures to an Underground Nuclear Detonation.

NOTE: The Seismic Safety data will be included in the USC&GS Technical Report VUF-3014

TECHNICAL REPORTS

Agency	Report No.	Subject or Title
SL	VUF-3012	Free-Field Particle Motions from a Nuclear Explosion in Salt - Part I
SRI	VUF-3013	Free-Field Particle Motions from a Nuclear Explosion in Salt - Part II
USC&GS	VUF-3014	Earth Vibration from a Nuclear Explosion in a Salt Dome
UED	VUF-3015	Compressional Velocity and Distance Measurements in a Salt Dome

LRL	VUF-3016	Design and Operation of a Chemical Processing Plant for Controlled Release of a Radioactive Gas from the Cavity of a Nuclear Explosion in Salt
LRL	PNE-3002 *	Response of Test Structures to Ground Motion from an Underground Nuclear Explosion
SRI	VUF-3017	Feasibility of Cavity Pressure and Temperature Measurements for a Decoupled Nuclear Explosion
LRL	VUF-3018	Background Engineering Data and Summary of Instrumentation for a Nuclear Test in Salt
WES	VUF-3019	Laboratory Design and Analyses and Field Control of Grouting Mixtures Employed at a Nuclear Test in Salt
LRL	VUF-3020	Geology and Physical and Chemical Properties of the Site for a Nuclear Explosion in Salt
EG&G	VUF-3021	Timing and Firing

* This report number was assigned by SAN

In addition to the reports listed above as scheduled for issuance by the Project DRIBBLE test organization, a number of papers covering interpretation of the SALMON data are to be submitted to the American Geophysical Union for publication. As of February 1, 1965, the list of these papers consists of the following:

Title	Author(s)	Agency(s)
Shock Wave Calculations of Salmon	L. A. Rogers	LRL
Nuclear Decoupling, Full and Partial	D. W. Patterson	LRL
Calculation of P-Wave Amplitudes for Salmon	D. L. Springer and W. D. Hurdlow	LRL
Travel Times and Amplitudes of Salmon Explosion	J. N. Jordan W. V. Mickey W. Helterbran	USC&GS AFTAC UED
Detection, Analysis and Interpretation of Teleseismic Signals from the Salmon Event	A. Archambeau and E. A. Flinn	SDC
Epicenter Locations of Salmon Event	E. Herrin and J. Taggart	SMU USC&GS
The Post-Explosion Environment Resulting from the Salmon Event	D. E. Rawson and S. M. Hansen	LRL
Measurements of the Crustal Structure in Mississippi	D. H. Warren J. H. Healy W. H. Jackson	USGS

All but the last paper in the above list will be read at the annual meeting of the American Geophysical Union in April 1965.

LIST OF ABBREVIATIONS FOR TECHNICAL AGENCIES

BR LTD	Barringer Research Limited Rexdale, Ontario, Canada
ERDL	Engineering Research Development Laboratory Fort Belvoir, Virginia
FAA	Federal Aviation Agency Los Angeles, California
GIMRADA	U. S. Army Geodesy, Intelli- gence and Mapping Research and Development Agency Fort Belvior, Virginia
H-NSC	Hazleton-Nuclear Science Corporation Palo Alto, California
H&N, INC	Holmes & Narver, Inc. Los Angeles, California Las Vegas, Nevada
II	Isotopes, Inc. Westwood, New Jersey
ITEK	Itek Corporation Palo Alto, California
JAB	John A. Blume & Associates Research Division San Francisco, California
LRL	Lawrence Radiation Laboratory Livermore, California
NRDL	U. S. Naval Radiological Defense Laboratory San Francisco, California
REECo	Reynolds Electrical & Engineering Co., Inc. Las Vegas, Nevada
RFB, INC.	R. F. Beers, Inc. Alexandria, Virginia
SDC	Seismic Data Center Alexandria, Virginia
EG&G	Edgerton, Germeshausen & Grier, Inc. Las Vegas, Nevada
SL	Sandia Laboratory Albuquerque, New Mexico
SMU	Southern Methodist University Dallas, Texas
SRI	Stanford Research Institute Menlo Park, California
TI	Texas Instruments, Inc. Dallas, Texas
UA	United Aircraft El Segundo, California
UED	United Electro Dynamics, Inc. Pasadena, California
USBM	U. S. Bureau of Mines Washington, 25, D. C.
USC&GS	U. S. Coast and Geodetic Survey Las Vegas, Nevada
USGS	U. S. Geologic Survey Denver, Colorado
USPHS	U. S. Public Health Service Las Vegas, Nevada
USWB	U. S. Weather Bureau Las Vegas, Nevada